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PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventor: PETER ARNOLD MERIGOLD

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COMPLETE SPECIFICATION

Improvements in or relating to Optical Objectives of Variable Equivalent Focal Length

We, THE RANK ORGANISATION LIMITED, a British Company of 11, Belgrave Road, London, S.W.1., do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to optical objectives of the "zoom" type, that is of the type having relatively movable members whereby under the control of a zoom control element the equivalent focal length of the objective can be continuously varied throughout a range, whilst maintaining constant position of the image plane, whereby the size of the image can be varied the objective being corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion throughout the range of variation.

In such objectives, accommodation for change of object distance is usually achieved by imparting an additional movement to the front member of the objective under the control of a focussing control element. This, however, involves mechanical difficulties, especially when the front member itself participates in the zooming relative movements, but even when such member does not so participate, so that its movements are confined to those required for focussing purposes, mechanical difficulties still arise when there is a wide range of variation of equivalent focal length, for in practice the front member must have a wide relative aperture and must also be of relatively complex structure in order to facilitate correction of the aberrations, not only throughout the zooming range, but also throughout the focussing range, and must consequently be quite bulky and heavy.

An improved focussing arrangement for a zoom objective wherein such difficulties are materially reduced, forms the subject of British Patent Specification No. 1,066,501. The objective according to the invention of said Patent specification comprises a front member which for a given object position remains stationary during the zooming relative movements, an assembly located behind the front member and incorporating the members of the objective movable for zooming purposes, and a stationary rear member, wherein the front member is divided into front and rear portions and focussing to suit different object positions is effected by axial movement only of the rear portion of the front member, the stationary front portion of the front member being approximately afocal (that is having an equivalent focal length numerically greater than $4f_A$, where f_A is the equivalent focal length of the complete front member for an infinitely distant object) and including a divergent element and a convergent element, whilst the rear portion of the front member is convergent and has an equivalent focal length between $0.75f_A$ and $1.15f_A$. In the preferred arrangement, the stationary front portion of the front member consists of a doublet component, whilst the movable rear portion thereof consists of two simple convergent components.

The construction of the front member according to Patent Specification No. 1,066,501 has the great advantage that only a relatively light portion thereof is moved for focussing purposes, thus considerably simplifying the mechanical problems involved in the focussing movement, and at the same time the arrangement also simplifies the problem of approximately stabilising the residual aberrations of the front member throughout a wide focussing range. Such stabilisation is effected by suitable dimensioning of the parts of the front member, so that the sum of the contributions of the individual surfaces of the front member to the various aberrations is approximately constant throughout the focussing range. If then the assembly behind the front member incorporating the members movable for zooming purposes is such as approximately to stabilise its aberra-

tions throughout the zooming range, it will be clear that the residual aberrations of the combination of the front member with such assembly will be approximately stabilised throughout both the focussing range and the zooming range and can be balanced out by suitable design of the stationary rear member of the objective. In practice, however, it is found that, although fairly good stabilisation of the aberrations throughout the focussing movement can be achieved with the front member of such prior arrangement, the level at which such stabilisation is effected presents difficulty in balancing out in the zooming assembly and in the stationary rear member.

The present invention has for its object to provide a zoom objective with an improved construction of the front member, wherein, whilst retaining the advantages of such prior arrangement, a higher standard of aberration stabilisation throughout the focussing range can be obtained and at a more convenient level.

The optical objective of the zoom type, according to the present invention, is corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and comprises a front member which for a given object position remains stationary during the zooming relative movements, an assembly located behind the front member and incorporating the members of the objective movable for zooming purposes, and a stationary rear member, wherein the front member is divided into three portions and focussing to suit different object positions is effected by axial movement only of the middle portion, the front and rear portions remaining stationary, each of such front and rear portions being divergent and having equivalent focal length between $1.5f_A$ and $7.5f_A$ (where f_A is the equivalent focal length of the complete front member when focussed for an infinitely distant object), whilst the movable middle portion is convergent and has equivalent focal length numerically lying between $0.25f_A$ and $1.0f_A$.

This arrangement of the front member has the advantage over that of the Patent specification above mentioned that it renders it possible to achieve a higher standard of aberration stabilisation throughout the focussing range, more especially in respect of the chromatic aberrations, for which stabilisation is facilitated by the use of a convergent portion between two divergent portions, and at the same time the provision of a stationary rear portion enables the general level of the stabilised aberrations to be adjusted to a more convenient value, whilst still retaining the advantage that only a relatively light portion of the front member is movable for focussing purposes.

Stabilisation of spherical aberration, coma and astigmatism, especially at the short focussing distances, can be assisted by making the rear surface of the stationary front portion of the front member convex to the front with radius of curvature lying between $0.5f_A$ and $2.0f_A$.

Although in some instances, when only a low relative aperture is required, such stationary front portion may consist only of a simple component, it will usually be preferable for such portion to comprise a doublet component having a dispersive internal contact, the mean refractive index of the material of the rear element of such component exceeding that of the front element thereof by between 0.05 and 0.15, whilst the Abbé V number of the material of the front element of such component exceeds that of the rear element thereof by more than 15. This assists in stabilisation throughout the focussing range of the chromatic aberrations, and especially of oblique chromatic aberration at the wide angle end of the zooming range. The arithmetic mean between the mean refractive indices of the materials of the two elements of such doublet component is preferably greater than 1.700, thereby assisting in the stabilisation of astigmatism, distortion and field curvature throughout the focussing range. Further assistance in the stabilisation of astigmatism ande oblique chromatic aberration can be obtained when the internal contact in such doublet component is concave to the front with radius of curvature greater than $2f_A$.

Whilst in some instances the movable middle portion of the front member may consist of a single compound component, such middle portion preferably consists of two convergent components, each having equivalent focal length between $0.75f_A$ and $1.5f_A$. In such case, the front surface of the front component of such middle portion is preferably convex to the front with radius of curvature between $0.5f_A$ and $2.5f_A$, the front surface of the rear component of such middle portion being convex to the front with radius of curvature between $0.25f_A$ and $1.25f_A$. These features contribute towards the stabilisation of spherical aberration, coma and astigmatism throughout the focussing range.

The two components of such middle portion are preferably simple components, the arithmetic mean between the mean refractive indices of the materials of such components lying between 1.575 and 1.700, and the arithmetic mean between the Abbé V numbers of such materials being greater than 50. This contributes towards stabilisation of astigmatism and oblique chromatic aberration throughout the focussing range.

It is desirable to locate the rear nodal point of the complete front member well to the rear and sometimes even beyond the rear surface of the front member, thus making it

possible, not only to accommodate the desired zooming movements of the members of the assembly behind the front member without risk of fouling between the front member and such assembly and with minimum increase in the overall length of the objective, but also to achieve a good compromise between the diameters and relative apertures of the individual members. For this purpose, the sum of the axial thicknesses of the two simple components of the middle portion of the front member preferably lies between $0.75f_A$ and $0.4f_A$.

The total axial movement of the middle portion of the front member within the focussing range preferably lies between 0.05 and 2.0 times the equivalent focal length of such middle portion. Such middle portion moves forwardly from the position for an infinitely distant object to the position corresponding to the shortest focussing distance.

The stationary rear portion of the front member, whilst it may be in the form of a compound component, preferably consists of a simple divergent component, whose rear surface is convex to the front with radius of curvature between $0.75f_A$ and $2.5f_A$, the mean refractive index of the material of such component being greater than 1.600. These features assist in enabling such rear portion to cooperate with the front and middle portions of the front member in producing good stabilisation throughout the focussing range of the residual aberrations at a level favourable to the aberration stabilisation throughout the zooming range to be achieved in the assembly behind the front member. Further assistance in this can be obtained by making the arithmetic mean of the Abbé V numbers of the materials of the front element of the front doublet component and of the rear simple component ofthe front member greater than 50.

The equivalent focal length f_A of the complete front member for an infinitely distant object preferably lies between 10 and 25 times the minimum value of the ratio between the equivalent focal length of the complete objective and the f-number of the objective (at full aperture) within the zooming range. This assists in enabling the overall dimensions of the objective and also the relative aperture of the front member to be kept relatively small.

The improved focussing arrangement according to the present invention is especially suitable for use in zoom objectives designed to give a very wide range of variation of the equivalent focal length of the objective. For instance, this focussing arrangement can be advantageously used in the zoom objective forming the subject of British Patent Specification No. 1,064,323, and still more so in the zoom objective forming the subject of British Patent Specification No. 1,109,912 (27526/65), which gives an even greater range of variation of the equivalent focal length of the objective.

Amongst features or groups of features, which may usefully be incorporated in a zoom objective of such type, and with any of which the focussing arrangement of the present invention can advantageously cooperate, may be mentioned:—

a) The minimum separation between the movable second and third members of the objective occurs when the equivalent focal length of the objective lies between a half and three-quarters of its maximum value in the range of variation, the equivalent focal lengths f_B and f_C respectively of such second and third members each lying numerically between 3 and 6 times the minimum value of the ratio of the equivalent focal length of the objective to the f-number of the objective (at full aperture) in the range of variation. These features assist generally in the stabilisation of the residual aberrations throughout the zooming range.

b) The movable divergent second member of the objective consists of a divergent meniscus compound component with its air exposed surfaces convex to the front followed by a divergent simple component, and performs in the range of variation a total axial movement lying numerically between $1.5f_B$ and $2.5f_B$ whilst the movable divergent third member of the objective consists of a divergent compound component followed by a simple divergent meniscus component with its surfaces concave to the front and performs in the range of variation a total axial movement lying numerically between $0.5f_C$ and $0.75f_C$. These features likewise assist generally in the stabilisation of the aberrations throughout the zooming range. It should be made clear that the phrase "total axial movement" means the axial distance between the positions of the member at the two ends of the zooming range.

c) The equivalent focal lengths of the front divergent compound component and of the rear divergent simple component of the movable second member respectively lie between $4f_B$ and $8f_B$ and between $0.75f_B$ and $2f_B$, whilst those of the front divergent compound component and of the rear divergent simple component of the movable third member each lie between $1.5f_C$ and $3f_C$. These features contribute to the stabilisation of astigmatism and distortion throughout the zooming range.

d) The front surface of the divergent simple component of the movable second member is concave to the front with a radius of curvature lying numerically between 2 and 4 times the radius of curvature of the rear surface of the divergent compound component of such second member, whilst the rear surface of the divergent compound com-

ponent of the movable divergent third member is convex to the front with radius of curvature numerically between 2 and 5 times that ofthe front surface of the divergent simple meniscus component of such third member. These features contribute to the stabilisation of coma throughout the zooming range.

e) The radius of curvature of the front surface of the divergent compound component of the movable second member lies numerically between $1.5f_B$ and $4f_B$, and the radius of curvature of the rear surface of such divergent compound component lies numerically between f_B and $2f_B$, whilst the radius of curvature of the internal contact in the divergent compound component of the movable third member (such component being a doublet component) lies numerically between $0.25f_C$ and f_C, such internal contact being concave to the front. These features contribute to the stabilisation of coma and astigmatism and are also helpful to the stabilisation of spherical aberration.

f) Each of the divergent compound components in the movable second and third members consists of a doublet component having a divergent element and a convergent element with a collective internal contact, the mean refractive index of the material of the convergent element exceeding that of the divergent element by between 0.05 and 0.20, whilst the Abbé V number of the material of the divergent element exceeds that of the convergent element by more than 25. These features contribute to the stabilisation of chromatic aberrations and assist also in the stabilisation of astigmatism.

g) The average value of the mean refractive indices of the materials of the divergent elements in each of the two movable members is greater than 1.625, and the average value of the Abbé V numbers of such materials is greater than 50. These features contribute to the stabilisation of astigmatism, chromatic aberrations and field curvature.

h) The radius of curvature of the front surface of the divergent simple meniscus component of the movable third member lies numerically between $0.75f_C$ and $2.5f_C$, whilst the front surface of the divergent compound component of such third member is concave to the front with radius of curvature numerically between f_C and $3f_C$. These features contribute to the stabilisation of coma and astigmatism.

It should be mentioned that a surface which at one point in the range of variation (whether for focussing or for zooming purposes) contributes strongly towards the control of one type of aberration may at a different point in the range contribute in a different manner, for example to the control of a different type of aberration. It must be recognised therefore that the functions above mentioned for individual features are the primary functions for which such features are intended and that in addition they may contribute usefully towards quite different functions.

In the accompanying drawings,

Figures 1, 2 and 3 respectively illustrate diagrammatically three convenient practical examples of zoom objective according to the present invention.

Numerical data for such three examples are given respectively in the three following tables, in which R_1 R_2 . . . . . designate the radii of curvature of the individual surfaces of the objective counting from the front, the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto, D_1 D_2 . . . . . designate the axial thicknesses of the individual elements of the objective, and S_1 S_2 . . . . . designate the axial air separations between the components of the objective. The tables also give the mean refractive indices n_d for the *d*-line of the spectrum and the Abbé V numbers of the materials from which the various elements of the objective are made, and in addition the clear diameters of the various surfaces of the objective.

The second section of each table gives the values of the three variable axial air separations between the four members of the objective, for a number of representative zooming positions, for which the corresponding values of the equivalent focal length F of the complete objective from its minimum value F_o to its maximum value F_m are also given, together with the corresponding values of log F.

The third section of each table gives, for each of a set of representative values of the distances *d* of the object in front of the front surfaces R_1 of the objective, the values of the two variable axial air separations between the three portions of the front member of the objective.

Two of the three examples include an aspheric surface, and the tables of such examples have a fourth section giving the equation defining an axial section through such aspheric surface.

The dimensions in all the tables are given in terms of the minimum equivalent focal length F_o.

In the first of the three examples, the members movable for zooming purposes are arranged in accordance with the invention of British Patent Specification No. 1,064,323. The objective according to this Patent specification has four members of which the first (counting from the front) for a given object distance remains stationary during the zooming relative movements, the second and third are divergent and movable, and the fourth is convergent and stationary, the minimum separation between the second and third members occurring when the equivalent focal length of the objective is greater than half

its maximum value in the range of variation, whilst the equivalent focal lengths f_B and f_C respectively of the movable second and third members lie numerically respectively between 4 and 8 times the minimum value of the ratio of the equivalent focal length of the objective to the f-number of the objective in the range of variation and between 5 and 10 times such minimum ratio, the divergent movable second member consisting of a divergent simple meniscus component with its surface convex to the front allowed by a divergent compound component and performing during the range of variation a total axial movement lying numerically between $1.5f_B$ and $2.5f_B$, whilst the divergent movable third member consists of a doublet component having a front surface concave to the front with radius of curvature lying numerically between $0.5f_C$ and $1.0f_C$ and performs during the range of variation a total axial movement lying numerically between $0.25f_C$ and $0.5f_C$.

EXAMPLE I

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number	Clear Diameter
R_1 + 8.9126				R_1 2.127
	D_1 0.1019	1.68868	49.63	
R_2 − 18.0832				R_2 2.124
	D_2 0.068	1.78456	26.10	
R_3 + 3.9783				R_3 2.036
	S_1 variable for focussing			
R_4 + 5.0561				R_4 2.043
	D_3 0.2122	1.62077	60.53	
R_5 − 5.0561				R_5 2.043
	S_2 0.0017			
R_6 + 2.1736				R_6 1.955
	D_4 0.2122	1.62093	60.44	
R_7 + 16.7001				R_7 1.950
	S_3 variable for focussing			
R_8 + 55.1268				R_8 1.935
	D_5 0.068	1.62018	60.38	
R_9 + 5.0911				R_9 1.861
	S_4 variable			
R_{10} + 2.2196				R_{10} 1.36
	D_6 0.045	1.6968	56.33	
R_{11} + 0.9714				R_{11} 1.185
	S_5 0.290			
R_{12} − 2.1975				R_{12} 1.177
	D_7 0.040	1.6968	56.33	
R_{13} + 2.4990				R_{13} 1.127
	D_8 0.170	1.78503	26.09	
R_{14} − 2.4990				R_{14} 1.116
	D_9 0.040	1.6968	56.33	
R_{15} + 4.5842				R_{15} 1.073
	S_6 variable			
R_{16} − 1.0424				R_{16} 0.624
	D_{10} 0.030	1.6968	56.33	
R_{17} + 1.0424				R_{17} 0.656
	D_{11} 0.085	1.78502	26.09	
R_{18} + 7.7833				R_{18} 0.664
	S_7 variable			
R_{19} stop				R_{19} 0.685
	S_8 0.050			
R_{20} + 3.4495				R_{20} 0.709
	D_{12} 0.100	1.52372	59.16	
R_{21} − 2.0422				R_{21} 0.721
	S_9 0.0025			
R_{22} + 1.1240				R_{22} 0.732
	D_{13} 0.100	1.52372	59.16	

EXAMPLE I (Continued)

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number	Clear Diameter
R_{23} + 19.8334				R_{23} 0.728
	S_{10} 0.0025			
R_{24} + 0.8336				R_{24} 0.709
	D_{14} 0.100	1.52372	59.16	
R_{25} + 2.4990				R_{25} 0.688
	S_{11} 0.1899			
R_{26} aspheric				R_{26} 0.605
	D_{15} 0.222	1.72874	28.67	
R_{27} + 0.6773				R_{27} 0.552
	S_{12} 0.254			
R_{28} + 1.8282				R_{28} 0.576
	D_{16} 0.05	1.72874	28.67	
R_{29} + 1.2010				R_{29} 0.576
	D_{17} 0.125	1.62041	60.29	
R_{30} − 1.3298				R_{30} 0.578

Axial air separations variable for zooming purposes.

S_4	S_6	S_7	F	log F
0.0267	1.6413	0.5252	1.0	0
0.5241	1.1259	0.5434	1.42	0.152
1.1803	0.4828	0.5303	2.53	0.403
1.6734	0.1288	0.3911	4.5	0.653
2.0027	0.1332	0.0574	8.0	0.903

Axial air separations variable for focussing purposes.

d	S_1	S_3
∞	0.2547	0.0408
250	0.2239	0.0716
100	0.1750	0.1205
40	0.0408	0.2547

Equation for aspheric surface R_{26}

$$x = -3.2667 + \sqrt{10.6713 - y^2} - 0.0375\,y^4 + 0.4903y^6 - 0.3653y^8 - 0.8664y^{10}$$

In this example, the maximum value of F_m of the equivalent focal length F of the objective in the zooming range of variation is eight times the minimum value F_o thereof. The example is corrected for a relative aperture of $f/4.0$. The back focal distance from the rear rear surface R_{30} of the objective to the image plane is 4.59 F_o. The length of the semi-diagonal of the rectangular image field is 0.4 F_o.

The objective covers a semi-angular field of view varying from 2.8 degrees at F_m to 21 degrees at F_o.

The front member includes the surfaces R_1—R_9, the movable second member the surfaces R_{10}—R_{15}, the movable third member the surfaces R_{16}—R_{18} and the stationary rear member the surfaces R_{20}—R_{30}.

The iris diaphragm, indicated in the above table by the reference R_{19}, is stationary and is located behind the movable third member and in front of the stationary rear member

The equivalent focal length f_A of the front member for an infinitely distant object is $+3.5638$ F_o, that f_B of the movable second member is -1.1762 F_o that f_C of the movable third member is -1.4541 F_o and that f_D of the stationary rear member is $+1.1813$ F_o, the positive and negative signs respectively indicating convergence and divergence.

The front member has a stationary divergent front portion including the surfaces R_1—R_3, a movable convergent middle portions including the surfaces R_4—R_7, and a stationary divergent rear portion including the surfaces R_8—R_9. The equivalent focal length of the front portion is -8.0804 F_o, that is numerically $2.268f_A$. The equivalent focal length of the movable middle portion is $+2.0386$ F_o, that is $0.572f_A$. The equivalent focal length of the stationary rear portion is -9.0359 F_o, that is numerically $2.535f_A$.

The stationary front portion of the front member consists of a divergent doublet component having a dispersible internal contact R_2. The radius of curvature R_3 of the rear surface of such portion is 3.9783 F_o or $1.12f_A$. The mean refractive index of the material of the divergent rear element of such component exceeds that of the convergent front element by 0.09588, whilst the Abbé V number of the material of the front element exceeds that of the rear element by 23.53. The arithmetic mean between the mean refractive indices of the materials of these two elements is 1.73662. The internal contact R_2 is concave to the front with radius of curvature 18.0832 F_o or $5.07f_A$.

The movable middle portion of the front member consists of two simple convergent components, the equivalent focal length of the front component being $+4.1054$ F_o or $1.15f_A$, whilst that of the rear component is $+4.0019$ F_o or $1.12f_A$. The radius of curvature of the front surface R_4 of the front component is 5.0561 F_o or $1.42f_A$, and that of the front surfaces R_6 of the rear component is 2.1736 F_o or $0.61f_A$, such surfaces both being convex to the front. The sum of the axial thicknesses of the two components is 0.4244 F_o or $0.12f_A$. The arithmetic mean between the mean refractive indices of the materials of the two components is 1.621 and the arithmetic mean between the Abbé V numbers of such materials is 60.5. The total axial movement of the middle portion is 0.2139 F_o, which is about 0.11 times the equivalent focal length of such middle portion.

The stationary rear portion of the front member is in the form of a simple divergent component, whose rear surface R_9 is convex to the front with radius of curvature 5.0911 F_o or $1.40f_A$.

The arithmetic mean between the Abbé V numbers of the materials of the front element of the front doublet component and of the rear simple component of the front member is 55.0.

The minimum value of the ratio of the equivalent focal length F of the complete objective to the f-number of the objective is 0.25 F_o, and the equivalent focal length f_A of the front member of the objective is 3.5638 F_o, which amounts to 14.3 times such minimum ratio.

Turning now to the remaining members of the objective concerned with the zooming movements, the second and third members of the objective, movable for zooming purposes, are each divergent and the stationary rear member is convergent.

The minimum separation between the second and third members occurs when the equivalent focal length of the objective is 5.96 F_o, or 0.745 F_m. The equivalent focal length f_B of the second member is numerically 4.70 times the minimum value of the ratio of the equivalent focal length F to the f-number of the objective, and the equivalent focal length f_C of the third member is numerically 5.82 times such minimum ratio. The second member performs a total axial movement equal to 1.9760 F_o or $1.68f_B$ in the zooming range, and the total axial movement of the third member is 0.4678 F_o or $0.32f_C$. During a zooming movement to increase the equivalent focal length of the objective, the second member moves rearwardly, whilst the third member at first moves a short distance forwardly and then a longer distance rearwardly.

The movable second member consists of a divergent simple meniscus component, whose front and rear surfaces R_{10} and R_{11} have radii of curvature respectively numerically equal to $1.89f_B$ and $0.83f_B$, followed by a divergent triplet component having a convergent element between two divergent elements. The radii of curvature of the front and rear surfaces R_{12} and R_{15} of such triplet

component are respectively numerically equal to $1.87f_B$ and $3.90f_B$. The three divergent elements of the second member are all made of the same material, whose Abbé V number exceeds that of the material of the convergent middle element of the triplet by 30.24, the mean refractive index of the latter material exceeding that of the former material by 0.088.

The movable third member consists of a divergent doublet component having a collective internal contact R_{17} whose radius of curvature is numerically equal to 0.72 f_C, the front surface R_{16} of such component having radius of curvature also equal to $0.72f_C$. The divergent front element of such component is made of the same material as the divergent elements of the second member, and the convergent rear element thereof of the same material as the convergent element of the second member.

The stationary rear member may take various forms, but in the example consists of three convergent simple components followed by a divergent simple component and a convergent doublet component having a divergent element in front of a convergent element. The front surface R_{26} of the divergent simple component is made aspheric and at its vertex is concave to the front with radius of curvature numerically equal to 3.2667 F_o.

In the example the residual aberrations of the front three members are well stabilised throughout the focussing and zooming ranges, and the arrangement chosen for the rear member is especially convenient for balancing out such residual aberrations, especially the primary aberrations, the aspheric surface assisting in correction of the higher order aberrations, especially spherical aberrations and coma. The zooming movements are such that there is an approximately logarithmic law interconnecting the variation of the equivalent focal length of the objective and the movement of the zooming control element so that a constant rate of movement of such element will produce an approximately constant rate of change of log F, thereby producing an approximately constant rate of growth of image size throughout the zooming range.

Still better aberration correction can be obtained throughout the foucssing range and through a much increased zooming range, by using the present invention in combination with the invention of British Patent Specification No. 1,109,912 (27526/65) and the second and third examples now to be described are both of this kind. The optical objective of the zoom type, in accordance with such copending application is corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and has four members, of which the first (counting from the front) is convergent and for a given object distance remains stationary during the zooming relative movements, the second and third are divergent and movable, and the fourth is convergent and stationary, the minimum separation between the second and third members occurring when the equivalent focal length of the objective lies between a half and three-quarters of its maximum value in the range of variation, the equivalent focal lengths f_B and f_C respectively of the movable second and third members each lying numerically between 3 and 6 times the minimum value of the ratio of the equivalent focal length of the objective to the f-number of the objective in the range of variation, the movable divergent second member consisting of a divergent meniscus compound component, with its air-exposed surfaces convex to the front, having equivalent focal length between $4f_B$ and $8f_B$, followed by a divergent simple component having equivalent focal length between $0.75f_B$ and $2f_B$, such second member performing in the range of variation a total axial movement lying numerically between $1.5f_B$ and $2.5f_B$, whilst the movable divergent third member consists of a divergent compound component having equivalent focal length between $1.5f_C$ and $3f_C$, followed by a divergent simple meniscus component with its surfaces concave to the front having equivalent focal length between $1.5f_C$ and $3f_C$, such third member performing in the range of variation a total axial movement lying numerically between $0.5f_C$ and $0.75f_C$.

EXAMPLE II

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number	Clear Diameter
R_1 + 10.5067				R_1 2.133
	D_1 0.12	1.68869	49.63	
R_2 − 21.3040				R_2 2.130
	D_2 0.08	1.78457	26.10	
R_3 + 4.6854				R_3 2.114
	S_1 variable for focussing			

EXAMPLE II—(*Continued*)

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number	Clear Diameter
R_4 + 5.9548				R_4 2.180
	D_3 0.25	1.62078	60.50	
R_5 − 5.9548				R_5 2.180
	S_2 0.002			
R_6 + 2.5600				R_6 2.103
	D_4 0.25	1.62094	60.44	
R_7 + 19.6616				R_7 2.078
	S_3 variable for focussing			
R_8 + 67,2000				R_8 2.057
	D_5 0.08	1.62109	60.38	
R_9 + 6.0200				R_9 1.988
	S_4 variable			
R_{10} + 2.6352				R_{10} 1.100
	D_6 0.033	1.69864	55.99	
R_{11} + 0.7174				R_{11} 0.968
	D_7 0.133	1.78478	26.09	
R_{12} + 1.4174				R_{12} 0.945
	S_5 0.117			
R_{13} − 3.2390				R_{13} 0.944
	D_8 0.033	1.69843	56.09	
R_{14} + 1.5127				R_{14} 0.891
	S_6 variable			
R_{15} − 1.5600				R_{15} 0.653
	D_9 0.093	1.78424	26.10	
R_{16} − 0.6703				R_{16} 0.663
	D_{10} 0.031	1.62304	57.05	
R_{17} + 4.3480				R_{17} 0.679
	S_7 0.058			
R_{18} − 1.3076				R_{18} 0.679
	D_{11} 0.031	1.69898	56.12	
R_{19} − 7.6946				R_{19} 0.703
	S_8 variable			
R_{20} stop				R_{20} 0.932
	S_9 0.02			
R_{21} + 4.6008				R_{21} 0.958
	D_{12} 0.128	1.48767	69.95	
R_{22} − 1.9183				R_{22} 0.970
	S_{10} 0.0016			
R_{23} + 2.7306				R_{23} 0.991
	D_{13} 0.108	1.51009	64.22	
R_{24} − 3.9054				R_{24} 0.991
	S_{11} 0.0016			
R_{25} aspheric				R_{25} 0.978
	D_{14} 0.108	1.51009	64.22	
R_{26} + 4.7862				R_{26} 0.960
	S_{12} 0.0016			
R_{27} + 1.0558				R_{27} 0.932
	D_{15} 0.192	1.48767	69.95	
R_{28} − 2.8624				R_{28} 0.907
	D_{16} 0.057	1.78483	26.09	
R_{29} + 2.0717				R_{29} 0.856
	S_{13} 0.700			
R_{30} + 1.1812				R_{30} 0.621
	D_{17} 0.054	1.69835	56.16	
R_{31} + 0.7017				R_{31} 0.588
	S_{14} 0.0454			
R_{32} + 1.8905				R_{32} 0.588
	D_{18} 0.06	1.70076	30.30	
R_{33} + 7.3882				R_{33} 0.580

Axial air separations variable for zooming purposes

S_4	S_6	S_8	F	log F
0.018	2.293	0.683	1.0	0
1.076	1.202	0.716	2.0	0.301
1.848	0.463	0.683	4.0	0.062
2.406	0.110	0.479	80	0.903
2.712	0.258	0.025	16.0	1.204

Axial air separations variable for focussing purposes

d	S_1	S_3
∞	0.30	0.048
250	0.2571	0.0909
150	0.2272	0.1208
75	0.148	0.200
48	0.048	0.30

Equation for aspheric surface R_{25}

$$x = 1.777 - \sqrt{3.160 - y^2} - 0.0089y^4 + 0.0219y^6 - 0.0039y^8 + 0.0676y^{10}$$

EXAMPLE III

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number	Clear Diameter
R_1 + 21.0134				R_1 4.266
	D_1 0.240	1.68869	49.62	
R_2 − 42.6080				R_2 4.260
	D_2 0.160	1.78457	26.10	
R_3 + 9.3708				R_3 4.227
	S_1 variable for focussing			
R_4 + 11.9096				R_4 4.360
	D_3 0.500	1.62078	60.50	
R_5 − 11.9096				R_5 4.360
	S_2 0.004			
R_6 + 5.1200				R_6 4.206
	D_4 0.500	1.62094	60.44	
R_7 + 39.3232				R_7 4.157
	S_3 variable for focussing			
R_8 +134.400				R_8 4.114
	D_5 0.160	1.62109	60.38	
R_9 + 12.0400				R_9 3.976
	S_4 variable			
R_{10} + 5.2704				R_{10} 2.199
	D_6 0.066	1.69864	55.99	
R_{11} + 1.4347				R_{11} 1.935
	D_7 0.2656	1.78478	26.09	
R_{12} + 2.8349				R_{12} 1.890
	S_5 0.2336			
R_{13} − 6.4781				R_{13} 1.888
	D_8 0.066	1.69843	56.09	
R_{14} + 3.0254				R_{14} 1.782
	S_6 variable			
R_{15} − 3.1201				R_{15} 1.306
	D_9 0.1864	1.78424	26.10	
R_{16} − 1.3406				R_{16} 1.326
	D_{10} 0.0624	1.62304	57.05	
R_{17} + 8.6960				R_{17} 1.358
	S_7 0.116			
R_{18} − 2.6152				R_{18} 1.358
	D_{11} 0.0624	1.69898	56.12	
R_{19} − 15.3891				R_{19} 1.406
	S_8 variable			
R_{20} stop				R_{20} 1.862
	S_9 0.144			
R_{21} − 9.7648				R_{21} 1.917
	D_{12} 0.240	1.51003	64.18	
R_{22} − 2.4504				R_{22} 1.954
	S_{10} 0.004			
R_{23} + 9.0738				R_{23} 2.014
	D_{13} 0.200	1.51003	64.18	
R_{24} − 6.5646				R_{24} 2.019
	S_{11} 0.004			
R_{25} + 3.3548				R_{25} 2.008
	D_{14} 0.464	1.51003	64.18	
R_{26} − 3.6480				R_{26} 1.966
	D_{15} 0.128	1.78467	26.08	
R_{27} + 46.400				R_{27} 1.935
	S_{12} 4.480			
R_{28} + 2.7072				R_{28} 1.523
	D_{16} 0.108	1.78467	26.08	
R_{29} + 1.4684				R_{29} 1.478
	D_{17} 0.360	1.51005	64.17	
R_{30} − 19.0144				R_{30} 1.467
	S_{13} 0.004			
R_{31} + 4.4476				R_{31} 1.456
	D_{18} 0.200	1.69935	41.13	
R_{32} − 56.2744				R_{32} 1.425

Axial air separations variable for zooming purposes

S_4	S_6	S_8	F	log F
0.036	4.586	1.367	1.0	0
2.152	2.404	1.433	2.0	0.301
3.697	0.926	1.367	4.0	0.602
4.811	0.220	0.958	8.0	0.903
5.424	0.516	0.050	16.0	1.204

Axial air separations variable for focussing purposes

d	S_1	S_8
∞	0.600	0.096
500	0.5142	0.1818
300	0.4544	0.2416
150	0.296	0.400
96	0.096	0.600

In each of these two example, the maximum value F_m of the equivalent focal length of the objective is sixteen times the minimum value F_o thereof.

Example II, in the lower part of the zooming range from F_o to 8.5 F_o, is corrected for a relative aperture of $f/4.0$. If such relative aperture were maintained throughout the zooming range, it would necessitate excessive diameters for the front member. Thus, for example, in a practical form of the example, in which F_o is 2½ inches, the components of the front member would need to have diameters greater than 10 inches in order to give a relative aperture of $f/4.0$ for the 40-inch equivalent focal length at the upper end of the zooming range, which is obviously undesirable from the viewpoint of bulk, weight and cost. In order to keep the front member diameters within convenient limits, the arrangement is such that the relative aperture reduces from $f/4.0$ at 8.5 F_o to $f/7.5$ at F_m at an approximately linear rate relatively to log F.

Example III may be regarded as a variant of Example II having a differently arranged stationary rear member, which has a magnification equal to a half that of the rear member of Example II, the whole system being scaled to give the same range of variation of equivalent focal length as Example II. As a result, Example III has a relative aperture of $f/2.0$ from F_o to 8.5 F_o, the relative aperture thereafter reducing (in approximately linear relationship to log F) to the value $f/3.75$ at F_m.

The back focal distance from the rear surface of the objective to the image plane is 2.3082 F_o in Example II and 1.964 F_o in Example III. In both examples, the objective covers a semi-angular field of view varying from 1.2 degrees at F_m to 17.75 degrees at F_o. The length of the diagonal of the rectangular image area is 0.64 F_o in both examples.

The front member includes the surfaces R_1—R_9, the movable second member the surfaces R_{10}—R_{14} and the movable third member the surfaces R_{15}—R_{19} in both examples, whilst the stationary rear member includes the surfaces R_{21}—R_{33} in Example II and R_{21}—R_{32} in Example III.

The iris diaphragm, indicated in each table by the reference R_{20}, is stationary and is located between the third member and the rear member at a distance in front of the front surface R_{21} of the rear member equal to 0.02 F_o in Example II and 0.144 F_o in Example III.

The equivalent focal length f_A of the front

member is +4.197 F_o in Example II and +8.394 F_o in Example III; that f_B of the moving second member is −1.2915 in Example II and −2.583 F_o in Example III; that f_C of the moving third member is −1.149 F_o in Example II and −2.298 F_o in Example III; and that f_D of the stationary rear member is +1.0775 F_o in Example II and +9.329 F_o in Example III; the positive and negative signs respectively indicating convergence and divergence.

The front member has a stationary divergent front portion including the surfaces R_1—R_3, a movable convergent middle portion including the surfaces R_4—R_7, and a stationary divergent rear portion including the surfaces R_8—R_9. The equivalent focal length of the front portion is −9.510 F_o in Example II and −19.92 F_o in Example III, that is numerically 2.266f_A in each case. The equivalent focal length of the moving middle portion is +2.401 F_o in Example II and +4.802 F_o in Example III, that is numerically 0.57f_A in each case. The equivalent focal length of the stationary rear portion is −10.65 F_o in Example II and −21.3 F_o in Example III, that is numerically 2.54f_A in each case.

The stationary front portion of the front member consists of a divergent doublet component having a dispersive internal contact R_2, whose radius of curvature is numerically 5.08f_A in each example. The radius of curvature of the rears surface R_3 of such portion is numerically 1.12f_A in each example. The mean refractive index of the material of the divergent rear element of such doublet component exceeds that of the convergent front element thereof by 0.09588 in each example, whilst the Abbé V number of the material of the front element exceeds that of the rear element by 23.53 in each example. The arithmetic mean between the mean refractive indices of these two materials is 1.73662.

The movable middle portion of the front member consists of two simple convergent components, the front component having equivalent focal length +4.84 F_o in Example II and +9.68 F_o in Example III or +1.15f_A in each case, whilst that of the rear component is +4.71 F_o in Example II and +9.42 F_o in Example III or 1.12f_A in each case. In both examples the radius of curvature of the front surface R_4 of the front component is 1.42f_A, and that of the front surface of the rear component R_6 is 0.61f_A. The sum of the axial thicknesses of the two components is 0.5 F_o in Example II and 1.0 F_o in Example III, that is 0.12f_A in each case. The arithmetic mean between the mean refractive indices of the materials of the two components is 1.621 and that between the Abbé V numbers of such materials is 60.5, in both examples. The total axial movement of such middle portion in the focussing range is 0.252 F_o in Example II and 0.504 F_o in Example III, amounting in each case to 0 105 times the equivalent focal length of the middle portion.

The stationary rear portion of the front member consists of a divergent simple component, whose rear surface R_9 has radius of curvature aqual to 1.43f_A.

The arithmetic mean between the Abbé V numbers of the materials of the front element of the front doublet component and of the rear simple component of the front member is 55.

The minimum value of the ratio of the equivalent focal length F of the complete objective to the f-number of the objective is 0.25 F_o in Example II and 0.5 F_o in Example III, and the equivalent focal length f_A, of the front member is 16.79 times such minimum ratio in each case.

The moving second and third members of the objective are each divergent and the stationary rear member is convergent. The minimum separation between the second and third members in the zooming range occurs in each example when the equivalent focal length F of the objective is 9.225 F_o, and amounts to 0.098 F_o in Example II and 0.196 F_o in Example III. The equivalent focal length f_B of the second member is numerically 5.17 times the minimum value of the ratio of the equivalent focal length F of the objective to the f-number of the objective in each example. The equivalent focal length f_C of the third member is numerically 4.60 times such minimum ratio in each example.

During a zooming movement to increase the equivalent focal length F of the objective, the second member moves rearwardly for the whole of the range and the third member moves forwardly for a short distance and then rearwardly to a position close to the iris diaphragm. The total axial movement of the second member is 2.694 F_o in Example II and 3.388 F_o in Example III that is 2.09f_B in each case, and that of the third member 0.638 F_o in Example II and 1.317 F_o in Example III, that is 0.57f_C in each case.

The movable second member consists of a divergent meniscus doublet component having equivalent focal length −6.65 F_o in Example II and −13.3 F_o in Example III, that is in each case 5.15f_B, followed by a divergent simple component having equivalent focal length −1.47 F_o in Example III and −2.94 F_o in Example III, that is in each case 1.14f_B. The radius of curvature of the front surface R_{13} of such simple component is 2.29 times that of the rear surface R_{12} of the doublet component. The radius of curvature of the front surface R_{10} of the doublet component is numerically 2.04f_B and that of the rear surface R_{12} thereof is numerically 1.10f_B. The doublet component consists of a divergent element in front of a collec-

tive element, the internal contact R_{11} being collective. The mean refractive index of the material of the convergent element exceeds that of the divergent element by 0.08614, and the Abbé V number of the divergent element exceeds that of the convergent element by 29.90. The average value of the mean refractive indices of the materials of the divergent element of such doublet component and of the divergent simple component is 1.69854, and the average value of the Abbé V numbers of such materials is 56.04.

The movable third member consists of a divergent doublet component, having equivalent focal length -2.47 F_o in Example II and -4.94 F_o in Example III or $2.16f_C$ in each case, followed by a divergent simple meniscus component having equivalent focal length -2.26 F_o in Example II and -4.52 F_o in Example III, or $1.97f_C$ in each case. The radius of curvature of the rear surface R_{17} of the doublet component is numerically 3.32 times that of the front surface R_{18} of the simple component. The doublet component has a convergent element in front of a divergent element with a collective internal contact R_{16} whose radius of curvature is numerically $0.58f_C$. The mean refractive index of the material of the convergent element in such doublet component exceeds that of the divergent element by 0.16120, and the Abbé V number of the material of the divergent element exceeds that of the convergent element by 30.95. The average value of the mean refractive indices of the materials of the divergent rear element of the doublet component and of the simple component is 1,66101 and the average value of the Abbé V numbers of such materials is 56.58. The radius of curvature of the front surface R_{18} of the simple component is numerically $1.14f_C$ and that of the front surface R_{15} of the doublet component is numerically $1.36f_C$.

The zooming movements of the second and third members are such that the variation of the equivalent focal length of the objective and the movement of the zooming control element are interrelated by an approximately logarithmic law, so that with a constant rate of movement of the control element log F varies at an approximately constant rate so that there is a fairly steady rate of growth of the image size throughout the zooming range. The various aberrations are well stabilised by the front three members throughout the zooming range and throughout the focussing range in both examples, and such residual stabilised aberrations are balanced out in the stationary rear member. The construction of such rear member may vary widely.

In Example II, the stationary rear member has been designed to have a strong telephoto characteristic in order to keep the forward projection of the objective from the image plane as short as possible. This member consists in turn from the front of three convergent simple components, a convergent doublet component having a dispersive internal contact R_{28}, a divergent simple component and a convergent simple component, with a relatively large air separation S_{13} between the doublet component and the divergent simple component. An aspheric surface is included to assist in the balancing out of some of the higher order aberrations, and in the example this aspheric surface is located at the front surface R_{25} of the third convergent simple component. Such aspheric surface is convex to the front at its vertex.

In Example III, a modified construction of rear member is used comprising two convergent simple components followed by two convergent doublet components and a convergent simple component. This rear member does not include an aspheric surface. Such rear member has a much greater equivalent focal length than that of Example II and has a magnification 1.104, half that of Example II, the geometrical dimensions of the front three members being double those of Example II, thus giving the same range of variation of the equivalent focal length of the objective as in Example II.

In both examples the standard of aberration correction is high, with only a relatively small falling off at the upper end of the range of variation of equivalent focal length, where it is least important, and there is little variation in the standard of aberration correction throughout the focussing range. The construction of the front member is such that its equivalent focal length varies little during the focussing movement and such variation is in fact compensated by the corresponding variation in the position of the rear nodal point of the front member.

It will be appreciated that the foregoing examples have been given by way of example only and that various modifications within the scope of the invention may be made. Thus, the construction of the three individual portions of the front member may vary. For instance, the stationary front portion thereof may consist in some instances, where a low relative aperture is sufficient, of a simple component instead of a compound component. The moving middle portion may have a compound component in place of either or each of the simple components, or in some instances may consist merely of one compound component. The stationary rear portion may consist of a compound component instead of a simple component. Again, the front member, arranged in accordance with the present invention, may be used in combination with types of zooming system other than those above described, but is especially advantageout when used in combination with the zooming system of Examples II and III.

WHAT WE CLAIM IS:—

1. An optical objective of the zoom type, corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and comprising a front member which for a given object position remains stationary during the zooming relative movements, an assembly located behind the front member and incorporating the members of the objective movable for zooming purposes, and a stationary rear member, wherein the front member is divided into three portions and focussing to suit different object positions is effected by axial movement only of the middle portion, the front and rear portions remaining stationary, each of such front and rear portions being divergent and having equivalent focal length numerically lying between 1.5 f_A and 7.5 f_A (where f_A is the equivalent focal length of the complete front member when focussed for an infinitely distant object), whilst the movable middle portion is convergent and has equivalent focal length numerically lying between 0.25 f_A and 1.0 f_A.

2. An optical objective as claimed in Claim 1, in which the rear surface of the stationary front portion of the front member is convex to the front with radius of curvature lying between 0.5 f_A and 2.0 f_A.

3. An optical objective as claimed in Claim 1 or Claim 2, in which the stationary front portion of the front member consists of a doublet component having a dispersive internal contact, the mean refractive index of the material of the rear element of such component exceeding that of the front element thereof by between 0.05 and 0.15, whilst the Abbé V number of the material of the front element of such component exceeds that of the rear element thereof by more than 15.

4. An optical objective as claimed in any one of Claims 1—3, in which the stationary front portion of the front member consists of a doublet component having a convergent element and a divergent element, the arithmetic mean between the mean refractive indices of the materials of such elements being greater than 1.700.

5. An optical objective as claimed in any one of Claims 1—4, in which the stationary front portion of the front member consists of a doublet component whose internal contact is concave to the front with radius of curvature greater than 2 f_A.

6. An optical objective as claimed in any one of Claims 1—5, in which the movable middle portion of the front member consists of two convergent components, each having equivalent focal length between 0.75 f_A and 1.5 f_A.

7. An optical objective as claimed in Claim 6, in which the front surface of the front component of the movable middle portion of the front member is convex to the front with radius of curvature between 0.5 f_A and 2.5 f_A, whilst the front surface of the rear component of such middle portion is convex to the front with radius of curvature between 0.25 f_A and 1.25 f_A.

8. An optical objective as claimed in any one of Claims 1—7, in which the movable middle portion of the front member consists of two simple convergent components, the sum of the axial thicknesses of such two components lying between 0.075 f_A and 0.4 f_A.

9. An optical objective as claimed in any one of Claims 1—8, in which the movable middle portion of the front member consists of two simple convergent components, the arithmetic mean between the mean refractive indices of the materials of such two components lying between 1.575 and 1.700, whilst the arithmetic means between the Abbé V numbers of such materials is greater than 50.

10. An optical objective as claimed in any one of Claims 1—9, in which the total axial movement of the movable middle portion of the front member within the focussing range lies between 0.05 and 2.0 times the equivalent focal length of such middle portion.

11. An optical objective as claimed in any one of Claims 1—10, in which the stationary rear portion of the front member consists of a simple divergent component whose rear surface is convex to the front with radius of curvature between 0.75 f_A and 2.5 f_A, the mean refractive index of the material of such component being greater than 1.600.

12. An optical objective as claimed in any one of Claims 1—11, in which the arithmetic mean between the Abbé V numbers of the materials of the front element of a doublet component constituting the front portion of the front member and of a simple component constituting the rear portion of the front member is greater than 50.

13. An optical objective as claimed in any one of Claims 1—12, in which the equivalent focal length f_A of the complete front member for an infinitely distant object lies between 10 and 25 times the minimum value of the ratio between the equivalent focal length of the complete objective and the f-number of the objective (at full aperture) in the zooming range.

14. An optical objective as claimed in any one of Claims 1—13, in which the stationary rear member of the objective is convergent, and the assembly incorporating the members movable for zooming purposes comprises two movable divergent members respectively constituting the second and third members of the objective.

15. An optical objective as claimed in Claim 14, in which the minimum separation between the movable second and third members of the objective occurs when the equiva-

lent focal length of the objective lies between a half and three-quarters of its maximum value in the range of variation, the equivalent focal lengths f_B and f_C respectively of such second and third members each lying numerically between 3 and 6 times the minimum value of the ratio of the equivalent focal length of the objective to the f-number of the objective (at full aperture) in the range of variation.

16. An optical objective as claimed in Claim 14 or Claim 15, in which the movable divergent second member of the objec- consists of a divergent meniscus compound component with its air-exposed surfaces convex to the front allowed by a divergent simple component and performs in the range of variation a total axial movement lying numerically between 1.5 and 2.5 times the equivalent focal length f_B of such second member, whilst the movable divergent third member consists of a divergent compound component followed by a simple divergent meniscus component with its surfaces concave to the front and performs in the range of variation a total axial movement lying numerically between 0.5 and 0.75 times the equivalent focal length f_C of such third member.

17. An optical objective as claimed in Claim 16, in which the equivalent focal lengths of the front divergent compound component and of the rear divergent simple component of the movable second member respectively lie between 4 f_B and 8 f_B and between 0.75 f_B and 2 f_B, whilst those of the front divergent compound component and of the rear divergent simple component of the movable third member each lie between 1.5 f_C and 3 f_C.

18. An optical objective as claimed in Claim 16 or Claim 17, in which the front surface of the divergent simple component of the movable second member is concave to the front with radius of curvature lying numerically between 2 and 4 times the radius of curvature of the rear surface of the divergent compound component of such second member, whilst the rear surface of the divergent compound component of the movable third member is convex to the front with radius of curvature numerically between 2 and 5 times that of the front surface of the divergent simple meniscus component of such third member.

19. An optical objective as claimed in any one of Claims 16—18, in which the radius of curvature of the front surface of the divergent compound component of the movable second member lies numerically between 1.5 f_B and 4 f_B, and the radius of curvature of the rear surface of such component lies numerically between f_B and 2 f_B, whilst the radius of curvature of the internal contact in the divergent compound component of the movable third member (such component consisting of a doublet component) lies numerically between 0.25 f_C and f_C, such internal contact being concave to the front.

20. An optical objective as claimed in any one of Claims 16—19, in which each of the divergent compound components in the movable second and third members consists of a doublet component having a divergent element and a convergent element with a collective internal contact, the mean refractive index of the material of the convergent element exceeding that of the divergent element by between 0.05 and 0.20, whilst the Abbé V number of the material of the divergent element exceeds that of the convergent element by more than 25.

21. An optical objective as claimed in any one of Claims 16—20, in which the radius of curvature of the front surface of the divergent simple component of the movable third member lies numerically between 0.75 f_C and 2.5 f_C, and the radius of curvature of the front surface of the divergent compound component of the third member lies numerically between f_C and 3 f_C, such front surface being concave to the front.

22. An optical objective as claimed in any one of Claims 14—21, in which the average value of the mean refractive indices of the materials of the divergent elements in each of the two movable members is greater than 1.625, and the average value of the Abbé V numbers of such material is greater than 50.

23. An optical objective as claimed in any one of Claims 1 to 14, in which the first three members of the objective have numerical data approximately in accordance with the first section of the following table, that is within the permissible limits of variation from such data specified in the second section of the table:—

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number
R_1 + 8.9126			
	D_1 0.1019	1.68868	49.63
R_2 − 18.0832			
	D_2 0.068	1.78456	26.10
R_3 + 3.9783			
	S_1 variable		
R_4 + 5.0561			
	D_3 0.2122	1.62077	60.53
R_5 − 5.0561			
	S_2 0.0017		
R_6 + 2.1736			
	D_4 0.2122	1.62095	60.44
R_7 + 16.7001			
	S_3 variable		
R_8 + 55.1268			
	D_5 0.068	1.62018	60.38
R_9 + 5.0911			
	S_4 variable		
R_{10} + 2.2196			
	D_6 0.045	1.6968	56.33
R_{11} + 0.9714			
	S_5 0.290		
R_{12} − 2.1975			
	D_7 0.040	1.6968	56.33
R_{13} + 2.4990			
	D_8 0.170	1.78503	26.09
R_{14} − 2.4990			
	D_9 0.040	1.6968	56.33
R_{15} + 4.5842			
	S_6 variable		
R_{16} − 1.0424			
	D_{10} 0.030	1.6968	56.33
R_{17} + 1.0424			
	D_{11} 0.085	1.78502	26.09
R_{18} + 7.7833			

The permissible limits of variation of the optical powers of the various surfaces are as follows:—

For each of the surfaces of the first member (from R_1 to R_9) $\pm$ $0.5/f_A$

For each of the surfaces of the second member (from R_{10} to R_{15}) $\pm$ $0.5/f_B$

For each of the surfaces of the third member (from R_{16} to R_{18}) $\pm$ $0.5/f_C$.

The permissible limits of variation of the axial thicknesses of the various elements, subject to the exclusion of variations giving rise to negative values and elements of impractical small thicknesses, are as follows:—

For each element of the first member (from D_1 to D_5) $\pm$ 0.05 f_A

For each element of the second member (from D_6 to D_9) $\pm$ 0.05 f_B

For each element of the third member (from D_{10} to D_{11}) $\pm$ 0.05 f_C.

The values of f_A, f_B and f_C are respectively +3.5638 F_o, −1.1762 F_o and −1.4541 F_o. The values of S_1 and S_3 for an infinitely distant object are respectively 0.2547 F_o and 0.0408 F_o. The value of S_4 varies from 0.0267 F_o at minimum equivalent focal length in the zooming range to 2.0027 F_o at maximum equivalent focal length in the range. The value of S_6 varies from 1.6413 F_o at minimum equivalent focal length in the range to 0.1332 F_o at maximum equivalent focal length in the range.

---

wherein R_1 R_2 .... designate the radii of curvature of the individual surfaces counting from the front, the positive sign indicating that the surface is convex to the front andthe negative sign that it is concave to the front; S_1 S_2 .... designate the axial air separations between the components; the third and fourth columns of the first section of the table give the mean refractive indices *nd*

for the d-line of the spectrum and the Abbé V numbers of the materials of which the the elements are made; all linear dimensions in the first section of the table are given in terms of the minimum value F_o of the equivalent focal length of the objective in the range of variation; the optical power of a surface is defined by the expression $(n^1-n)/R$, where n^1 and n are the mean refractive indices of the material respectively behind and in front of the surface, and R is the radius of curvature of the surface taking account of its sign.

24. An optical objective as claimed in any one of Claims 1 to 22, in which the first three members of the objective have numerical data approximately in accordance with the first section of the following table, that is within the permissible limits of variation from such data specified in the second section of the table:

Radius	Thickness or Air Separation	Refractive Index n_d	Abbé V Number
R_1 + 10.5067			
	D_1 0.12	1.68869	49.63
R_2 − 21.3040			
	D_2 0.08	1.78457	26.10
R_3 + 4.6854			
	S_1 variable		
R_4 + 5.9548			
	D_3 0.25	1.62078	60.50
R_5 − 5.9548			
	S_2 0.002		
R_6 + 2.5600			
	D_4 0.25	1.62094	60.44
R_7 + 19.6616			
	S_3 variable		
R_8 + 67.2000			
	D_5 0.08	1.62109	60.38
R_9 + 6.0200			
	S_4 variable		
R_{10} + 2.6352			
	D_6 0.033	1.69864	55.99
R_{11} + 0.7174			
	D_7 0.133	1.78478	26.09
R_{12} + 1.4174			
	S_5 0.117		
R_{13} − 3.2390			
	D_8 0.033	1.69843	56.09
R_{14} + 1.5127			
	S_6 variable		
R_{15} − 1.5600			
	D_9 0.093	1.78424	26.10
R_{16} − 0.6703			
	D_{10} 0.031	1.62304	57.05
R_{17} + 4.3480			
	S_7 0.058		
R_{18} − 1.3076			
	D_{11} 0.031	1.69898	56.12
R_{19} − 7.6946			

The permissible limits of variation of the optical powers of the various surfaces are as follows:—

For each of the surfaces of the first member (from R_1 to R_9) $\pm$ $0.5/f_A$

For each of the surfaces of the second member (from R_{10} to R_{14}) $\pm$ $0.5/f_B$

For each of the surfaces of the third member (from R_{15} to R_{19}) $\pm$ $0.5/f_C$.

The permissible limits of variation of the axial thicknesses of the various elements, subject to the exclusion of variations giving rise to negative values and elements of impractical small thicknesses, are as follows:—

For each element of the first member (from D_1 to D_5) $\pm$ 0.05 f_A

For each element of the second member (from D_6 to D_8) $\pm$ 0.05 f_B

For each element of the third member (from D_9 to D_{11}) $\pm$ 0.05 f_O.

The values of f_A, f_B and f_O are respectively +4.197 F_o, −1.2915 F_o and −1.149 F_o. The values of S_1 and S_3 for an infinitely distant object are respectively 0.30 F_o and 0.048 F_o. The values of S_4 varies from 0.018 F_o at minimum equivalent focal length in the zooming range to 2.712 F_o at maximum equivalent focal length in the range. The value of S_6 varies from 2.293 F_o at minimum equivalent focal length in the range to 0.258 F_o at maximum equivalent focal length in the range.

Wherein R_1 R_2 .... designate the radii of curvature of the individual surfaces counting from the front, the positive sign indicating that the surface is convex to the front and the negative sign that it is concave to the front; D_1 D_2 .... designate the axial thicknesses of the individual elements; S_1 S_2 .... designate the axial air separations between the components: the third and fourth columns of the first section of the table give the mean refractive indices n_d for the *d*-line of the spectrum and the Abbé V numbers of the materials of which the elements are made; all linear dimensions in the first section of the table are given in terms of the minimum value F_o of the equivalent focal length of the objective in the range of variation; the optical power of a surface is defined by the expression $(n^1 - n)/R$, where n^1 and n are the mean refractive indices of the materials respectively behind and in front of the surface, and R is the radius of curvature of the surface taking account of its sign.

H. G. AMANN,
Agent for the Applicants.

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Fig. 1.

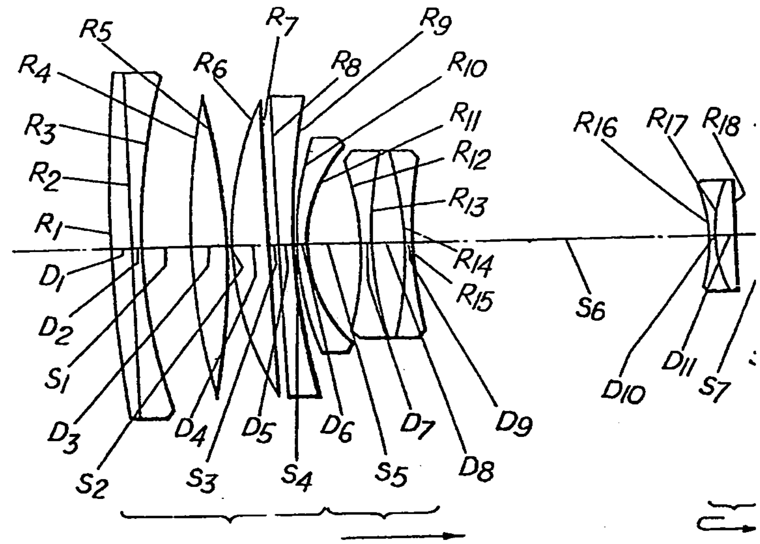
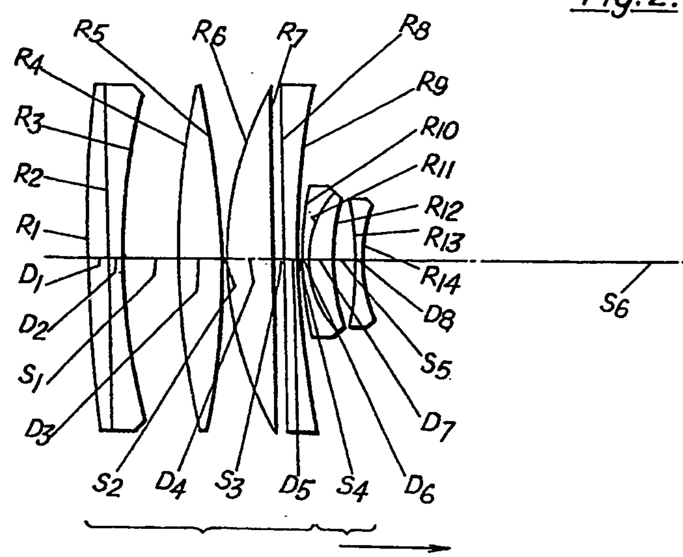

R5
R4
R3
R2
R1
D1
D2
S1
D3
S2
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
D4
S3
D5
S4
D6
S5
D7
D8
D9
R16
R17
R18
S6
D10
D11
S7

Fig. 2.


R5
R4
R3
R2
R1
D1
D2
S1
D3
S2
D4
S3
D5
S4
D6
R6
R7
R8
R9
R10
R11
R12
R13
R14
D8
S5
D7
S6

1,109,913 COMPLETE SPECIFICATION
2 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEET 1

Fig. 1.

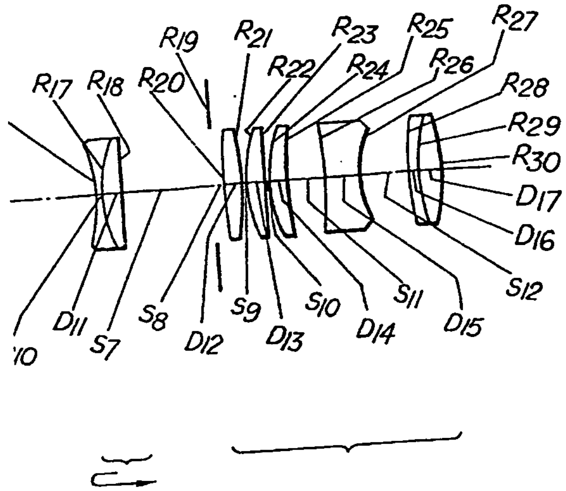


Fig. 2.

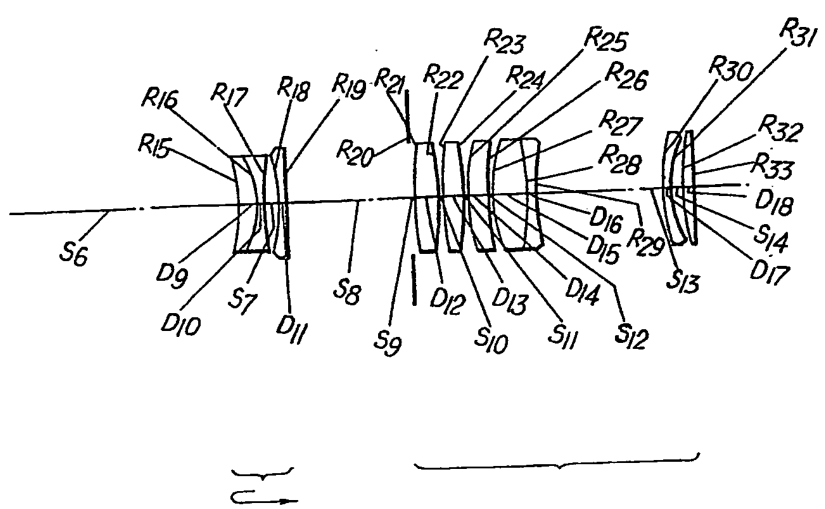


Fig. 1.

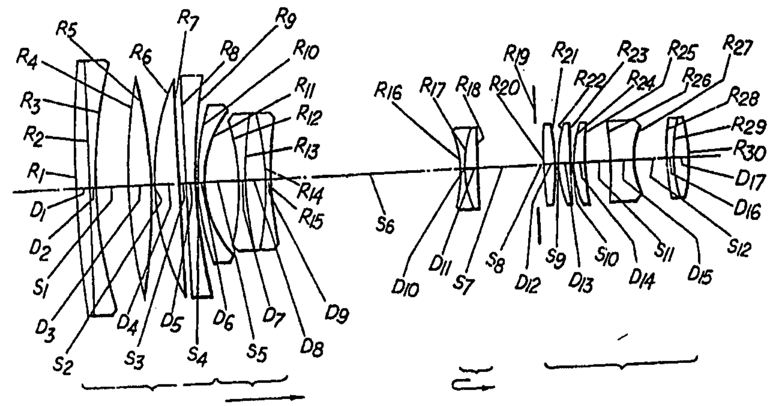
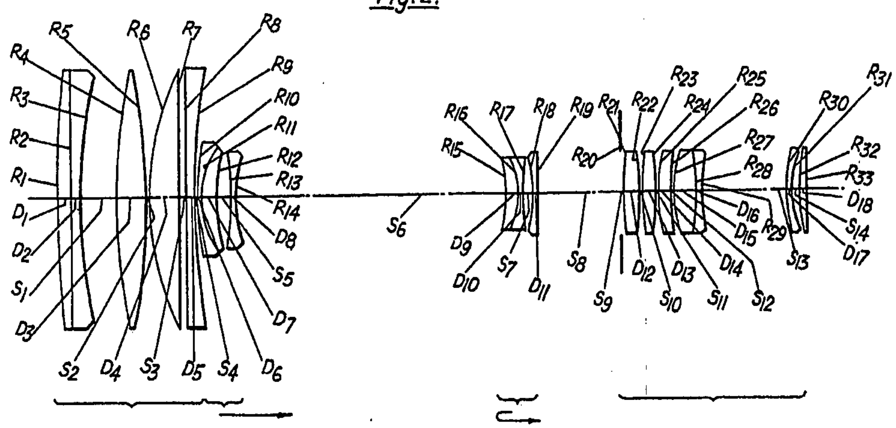
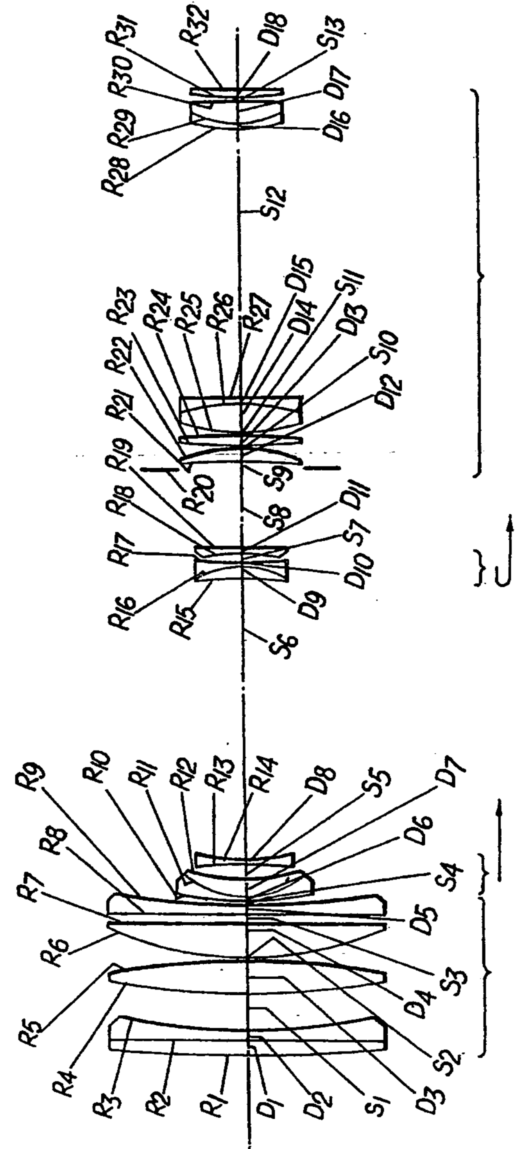

R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27 R28 R29 R30
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12

Fig. 2.


R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27 R28 R29 R30 R31 R32 R33
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16 D17 D18
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14

1,109,913 COMPLETE SPECIFICATION
2 SHEETS *This drawing is a reproduction of the Original on a reduced scale.*
SHEET 2



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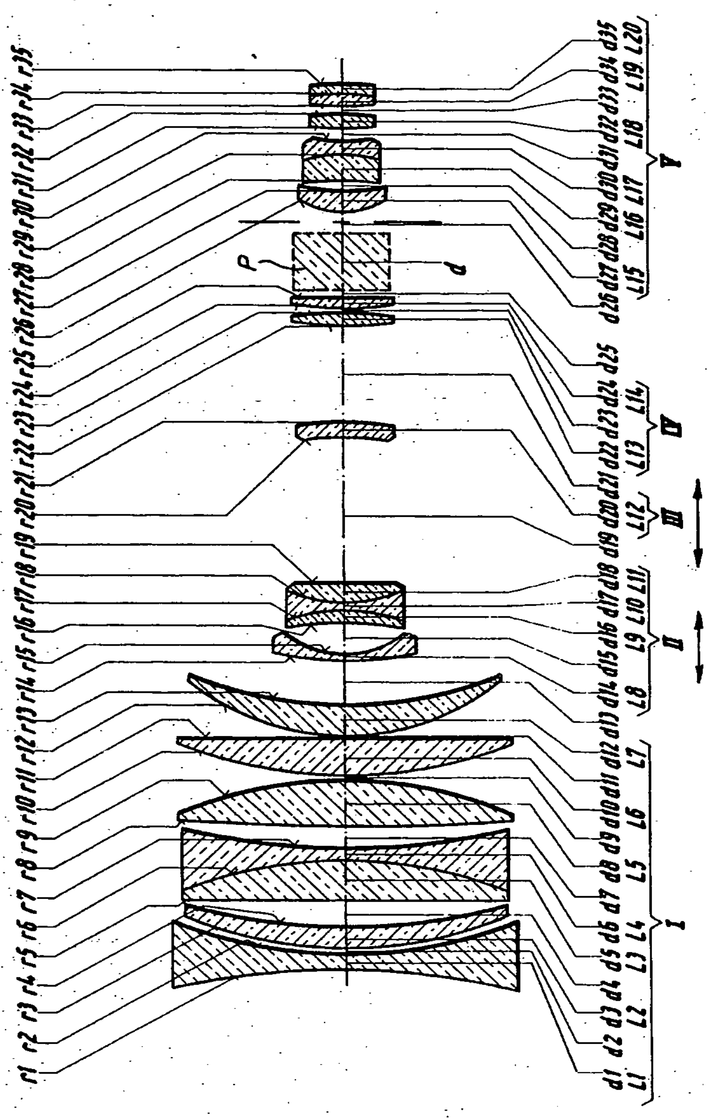

FIG. 1

Karl Macher
Inventor
By Karl G. Ross
Attorney

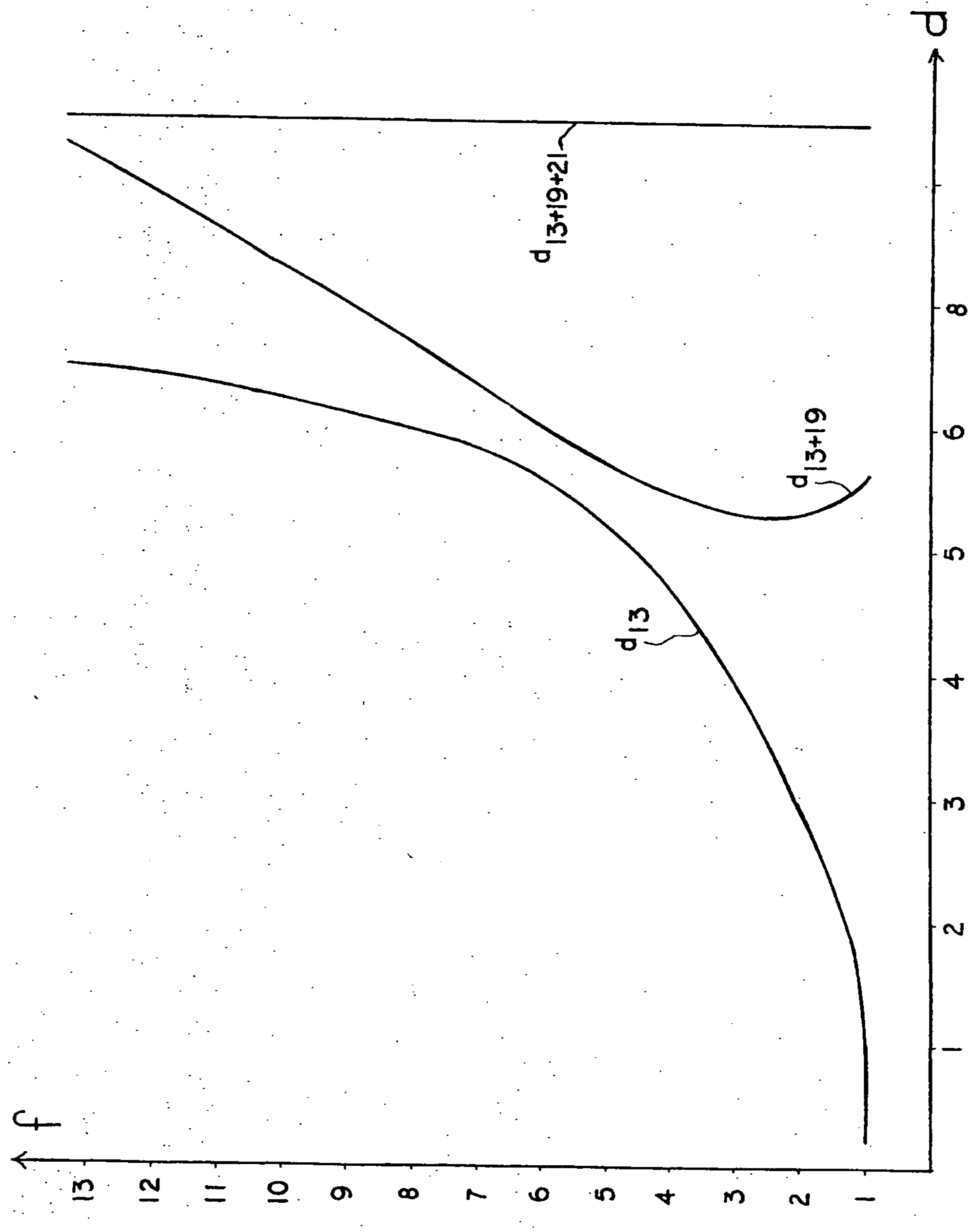

FIG. 2

Karl Macher
INVENTOR.

by *Karl F. Ross*

Attorney